The Sudoku for Selection of a New Refinery Site Using Transportation Problem: A Case of American Oil Industry

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Abstract

A transportation problem is in general concerned with the use or allocation of scarce resources such as labor, materials, machine-time and capital in the best possible manner, so that either costs are minimized or profits are maximized. However the real life situation often, differs from the theoretical one.

In the allocation of resources one often has to consider various other influencing parameters which play a dominant role in the decision making process. The decision is often not only minimization of costs or maximization of profits but could be as complex as maximization of profit through minimization of costs which can be achieved through in-house production of the viable components and outsourcing of the non-viable ones. This again brings in many additional sub-decisions like choice of the supplier, the technical contract to be entered into, the payment mechanisms and the service level agreement etc. The judicious mix of all these sub-decisions go into the crafting of a master decision which often decides whether the core competence of most economic production is maintained.

The objective of this paper is to seek a holistic understanding of the transportation problem which has wide applications across the industry and a reasonable understanding of the decision making process while undertaking a production or outsourcing decision. We have chosen Texaco Corporation for our study.

Key words-

*T*ransportation Problem, Linear Programming, Optimal Solution,North-West corner Method (NWCM), Vogel's Approximation Method (VAM), MODI method, Decision Making, Dummy variable

Introduction

In mathematics and economics, transportation theory is a name given to the study of optimal transportation and allocation of resources. The problem was formalized by the French mathematician Gaspard Monge in 1781. Major advances were made in this field during World War II by the Russian mathematician and economist Leonid Kantorovich. Consequently, the problem as it is now sometimes known as the Monge-Kantorovich transportation problem.

It is a type of linear programming problem that may be solved using a simplified version of the simplex technique called transportation method. Because of its major application in solving problems involving several product sources and several destinations of products, this type of problem is frequently called the transportation problem. It gets its name from its application to problems involving transporting products from several sources to several locations.

The formation can be used to represent more general assignment, scheduling problems as well as transportation and distribution problems. The two common objectives of such problems are either (1) minimize the cost of shipping *m* units to *n* destinations or (2) maximize the profit of shipping *m* units to *n* destinations.

General Description of a Transportation Problem

- A set of *m supply points* from which a good is shipped. Supply point *i* can supply at most s_i units.
- A set of *n demand points* to which the good is shipped. Demand point *j* must receive at least d_i units of the shipped good.
- Each unit produced at supply point *i* and shipped to demand point *j* incurs a *variable cost* of c_{ij}.
- X_{ij}= number of units shipped from *supply point i* to *demand point j*

Determine the amount x_{ij} to be transported between each origin-destination pair, i=1,......, m; j=1,........,n to satisfy the transportation requirements and minimize the total cost.

$$
\begin{array}{cccc|c}
X_{11} & X_{12} & \cdots & X_{1n} & a_1 \\
X_{21} & X_{22} & \cdots & X_{2n} & a_2 \\
\vdots & \vdots & & \vdots & \vdots \\
X_{m1} & X_{m2} & \cdots & X_{mn} & a_m \\
\hline
b_1 & b_2 & \cdots & b_n &
\end{array}
$$

$$\sum_{j=1}^{n} x_{ij} = a_i \quad \sum_{i=1}^{m} x_{ij} = b_j$$

$$\text{Total cost} = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} x_{ij} = f(\bar{x})$$

The transportation problem can be mathematically modelled as

Minimize f ($\bar{x}$)
subject to;

$$\sum_{j=1}^{n} x_{ij} = a_i \quad , j = 1, 2, ...,m$$

$$\sum_{i=1}^{m} x_{ij} = b_j \quad , j = 1, 2, ...,n$$

$x_{ij} \geq 0$, i = 1,.....,m ; j = 1,.....,n

Balanced Transportation Problem

If Total Supply equals Total Demand, the problem is said to be a balanced Transportation Problem.

- **Balancing a TP if total supply exceeds total demand**

If total supply exceeds total demand, we can balance the problem by adding dummy demand point. Since shipments to the dummy demand point are not real, they are assigned a cost of zero.

- **Balancing a TP if total supply is less than total demand**
  If a TP has a total supply that is strictly less than total demand the problem has no feasible solution. There is no doubt that in such a case one or more of the demand will be left unmet. Generally in such situations a penalty cost is often associated with unmet demand and as one can guess this time the total penalty cost is desired to be minimized.
- **Finding a basic feasible solution for a TP**
  Unlike other Linear Programming problems, a *balanced* TP with m supply points and n demand points is easier to solve, although it has m + n equality constraints. The reason for that is, if a set of decision variables (x_{ij}'s) satisfy all but one constraint, the values for x_{ij}'s will satisfy that remaining constraint automatically.

Objectives of the Study

- To satisfy the demand at destinations from the supply constraints at the minimum transportation cost possible.
- To know the quantity of available supplies and the quantities demanded.
- To find the best location for a new refinery site.
- To find the cost of transporting one unit of commodity from the place of origin to the destination.

About the Company

Texaco is the name of an American oil retail giant. Its flagship product is its fuel. It also owns the Havoline motor oil brand. Texaco was an independent company till it merged into Chevron Corporation in 2001. It began as the Texas Fuel Company, founded in 1901 in Beaumont, Texas by Joseph S. Cullinan, Thomas J. Donoghue, Walter Benona Sharp, and Arnold Schlat upon discovery of oil at Spindletop. For many years, Texaco was the only company selling gasoline in all 50 states, but this is no longer true. Its logo features a white star in a red circle.
Texaco gasoline comes with Techron, an additive developed by Chevron, as of 2005, replacing the previous Clean System3. The Texaco brand is strong in the US, Latin America and West Africa. It has a presence in Europe as well.
With the funds generated through various strategic moves, Texaco could now increase its budget for overseas exploration and production. Seeking to increase production by 125,000 barrels a day by the end of the decade, Texaco began to pursue opportunities in Russia, China, and Colombia. In order to minimize its exposure in such risky areas of operations as Russia, Texaco, like other oil majors, turned to joint ventures with its competitors. For instance, Texaco formed the Timan Pechora Company L.L.C. with Exxon, Amoco, and Norsk Hydro to negotiate a production-sharing agreement with Russia for the Timan Pechora Basin, which may hold more than two billion barrels of oil.

The much leaner Texaco of the mid-1990s had yet to return to its former glory, but was in better shape than in many years. One positive sign was Texaco's re-entry into the Canadian market in 1995 with its $30 million reacquisition of Texaco Canada Petroleum Inc. With the company committed to increasing its capital spending overseas from 45 percent of total capital spending to 55 percent by 1998, Texaco seemed determined to get its share of the oil available outside the

United States increased. Whether, that would be enough for Texaco, to recapture its past glory, in a decade of heated competition, remained to be seen.

Problem Background

The Texaco Corporation is a large, fully integrated petroleum company based in the United States. It's extensive distribution network is used to transport the oil to the company's refineries and then to transport the petroleum products from the refineries to Texaco's distribution centres. The locations of these various facilities are given in Table 1.

Texaco is continuing to increase market share for several of its major products. Therefore, management has made the decision to expand output by building an additional refinery. The crucial decision remains where to locate the new refinery?

The addition of a new refinery will have a great impact on the operation of the entire distribution system, including decisions on how much crude oil to be transported from each of its sources to each refinery (including this new one) and how much finished product to ship from each refinery to each distribution centre.

Therefore, the three key factors influencing management's decision on the location of the new refinery are:

1. The cost of transporting the oil from its sources to all the refineries, including the new one.
2. The cost of transporting finished product from all the refineries, including the new one, to the distribution centres.
3. Operating costs for the new refinery, including labour costs, taxes, the cost of needed supplies (other than crude oil), energy costs, the cost of insurance, the effect of financial incentives provided by the state or city, and so on so forth. (Capitol costs are not a factor since they would be essentially the same at any of the potential sites.)

Table 1: Location of Texaco's current facilities

Type of Facility	Locations
Oil Fields	1. Texas
	2. California
	3. Alaska
Refineries	1. Near Charleston, South Carolina
	2. Near Seattle, Washington
Distribution Centres	1. Pittsburgh, Pennsylvania
	2. Atlanta, Georgia
	3. Kansas City, Missouri
	4. San Francisco, California

Table 2: Potential Sites for Texaco's new refineries and their main advantages

Potential Site	Main Advantages
Near Los Angeles, California	Near California oil fields Ready access from Alaska oil fields Fairly near San Francisco distribution centre
Near Galveston, Texas	Near Texas oil fields Near corporate headquarters
Near St. Louis, Missouri	Low operating costs Centrally located distribution centres Ready access to crude oil via Mississippi River

Management has to set up a task force to study the issue of where to locate the new refinery. After considerable investigation, the task force has determined that there are three attractive potential sites. These sites and the main advantages of each are spelled out in Table 2. Other relevant factors, such as standard-of-living considerations for management and employees, are considered reasonably comparable at these sites.

Data Collection

The task force needs to gather a large amount of data, some of which requires considerable digging, in order to perform the analysis requested by management. Management wants

all the refineries, including the new one, to operate at full capacity. Therefore, the task force begins by determining how much crude oil each refinery would need to receive annually under these conditions. Using units of 1 million barrels, these needed amounts are shown on the left side of Table 3. The right side of the table shows the current annual output of crude oil from the various oil fields. These quantities are expected to remain stable for some years to come. The refineries need a total of 150 million barrels of crude oil, which will be produced in Texas, California and Alaska.

Table 3: Production data for Texaco Corp:

Refinery	**Crude Oil Needed Annually (Million Barrels)**
Charleston	20
Seattle	95
New One	35
Total	**150**

Oil Fields	**Crude Oil Produced Annually (Million Barrels)**
Texas	50
California	40
Alaska	60
Total	150

Since the amounts of crude oil produced or purchased will be the same regardless of which location is chosen for the new refinery, the task force concludes that the associated production or purchase costs (exclusive of shipping costs) are not relevant to the site selection decision. On the other hand, the costs for transporting the crude oil from its source to a refinery are very relevant. These costs are shown in Table 4 for both the three current refineries and the three potential sites for the new refinery.

Also very relevant are the costs of shipping the finished product from a refinery to a distribution centre. These costs are given in table 5.

The final key body of data involves the *operating* costs for a refinery at each potential site. Estimating these costs requires site visits by several members of the task force to collect detailed information about local labor costs, taxes, and so on so forth. Comparisons then are made with the operating costs of the current refineries to help refine these data.

In addition, the task force gathers information on one-time site costs for land, construction, and so on so forth, and amortizes these costs on an equivalent uniform annual cost basis. This process leads to the estimates shown in Table 6.

Problem Formulation

Armed with these data, the task force now needs to develop the following key financial information for management:

1. Total shipping cost for crude oil with each potential choice of a site for the new refinery.

2. Total shipping cost for finished product with each potential choice of a site for the new refinery.

For both types of costs, once a site is selected, an optimal shipping plan will be determined and then followed. Therefore, to find either type of cost with a *potential* choice of a site, it is necessary to solve the optimal shipping plan given that choice and then calculate the corresponding cost.

Table 4: Cost data for shipping crude oil to a Texaco refinery

Cost per Unit Shipped					
(Millions of $ per Million Barrels)					
Refinery or Potential Refinery					
	Charleston	Seattle	Los Angeles	Galveston	St. Louis
Texas	6	4	1	3	5
California	3	8	7	9	9
Alaska	4	4	2	6	2

Table 5: Estimated shipping costs for a Texaco refinery at each potential site

Site	Total Shipping Cost (Billions of $)
Los Angeles	1.57
Galveston	1.63
St. Louis	1.43

Table 6: Estimated operating costs for a Texaco refinery at each potential site

Site	Annual Operating Cost (Millions of $)
Los Angeles	620
Galveston	570
St. Louis	530

The task force recognizes that the problem of finding an optimal shipping plan for a given choice of a site is just a transportation problem. In particular, for shipping crude oil, Fig. 1 shows the spreadsheet model for this transportation problem, where the entries in the data cells come directly from Tables 3 and 4.

Problem Solution using Transportation

(I)
ON CONSIDERING LOS ANGELES SOLVING USING N/W CORNER RULE & MODI METHOD

Table-7.1

FROM ↓ / TO →	CHARLESTON	SEATTLE	LOS ANGELES	SUPPLY
TEXAS	20 [6]	30 [4]	[1]	50
CALIFORNIA	[3]	40 [8]	[7]	40
ALASKA	[4]	25 [4]	35 [2]	60
DEMAND	20	95	35	150

Table-7.2

FROM ↓ / TO →	CHARLESTON	SEATTLE	LOS ANGELES	SUPPLY	U_i
TEXAS	20 [6] -	30 [4] +	[1] -1	50	0
CALIFORNIA	[3] -7 +	40 [8] -	[7] +1	40	4
ALASKA	[4] -2	25 [4]	35 [2]	60	0
DEMAND	20	95	35	150	
V_j	6	4	2		

Table-7.3

FROM ↓ / TO →	CHARLESTON	SEATTLE	LOS ANGELES	SUPPLY	U_i
TEXAS	[6] +7	50 [4] +	[1] 1 -	50	0
CALIFORNIA	20 [3]	20 [8]	[7] -1	40	4
ALASKA	[4] +5	25 [4] +	35 [2] -	60	0
DEMAND	20	95	35	150	
V_j	-1	4	2		

Table-7.4

FROM ↓ / TO →	CHARLESTON	SEATTLE	LOS ANGELES	SUPPLY	Uᵢ
TEXAS	[6] +7	50 [4]	35 [1]	50	0
CALIFORNIA	20 [3]	20 [8]	[7] +2	40	4
ALASKA	[4] +5	60 [4]	[2] +1	60	0
DEMAND	20	95	35	150	
Vⱼ	-1	4	2		**695**

Therefore if we were to choose Los Angeles, the cost of shipping would be 695 million USD.

(II)

ON CONSIDERING GALVESTONSOLVING USING N/W CORNER RULE & MODI METHOD

Table-7.5

FROM ↓ / TO →	CHARLESTON	SEATTLE	GALVESTON	SUPPLY
TEXAS	20 [6]	30 [4]	[3]	50
CALIFORNIA	[3]	40 [8]	[9]	40
ALASKA	[4]	25 [4]	35 [6]	60
DEMAND	20	95	35	150

Table-7.6

FROM ↓ / TO →	CHARLESTON	SEATTLE	GALVESTON	SUPPLY	Uᵢ
TEXAS	20 [6]	30 [4]	[3] +1	50	0
CALIFORNIA	[3] -7	40 [8]	[9] +3	40	4
ALASKA	[4] -2	25 [4]	35 [6]	60	0
DEMAND	20	95	35	150	
Vⱼ	6	4	6		

Table-7.7

FROM ↓ / TO →	CHARLESTON	SEATTLE	GALVESTON	SUPPLY	Uᵢ
TEXAS	[6] +7	50 [4]	[3] +1	50	0
CALIFORNIA	20 [3]	20 [8]	[9] +3	40	4
ALASKA	[4] +5	25 [4]	35 [6]	60	0
DEMAND	20	95	35	150	
Vⱼ	-1	4	6		**730**

Therefore if we were to choose Galveston, the cost of shipping would be 730 million USD.

(III)

ON CONSIDERING St. LOUIS SOLVING USING N/W CORNER RULE & MODI METHOD

Table-7.8

FROM ↓ / TO →	CHARLESTON	SEATTLE	St. LOUIS	SUPPLY
TEXAS	20 [6]	30 [4]	[5]	50
CALIFORNIA	[3]	40 [8]	[9]	40
ALASKA	[4]	25 [4]	35 [2]	60
DEMAND	20	95	35	150

Table-7.9

FROM ↓ / TO →	CHARLESTON	SEATTLE	LOS ANGELES	SUPPLY	Uᵢ
TEXAS	20 [6]	30 [4]	[5] +3	50	0
CALIFORNIA	[3] -7	40 [8]	[9] +3	40	4
ALASKA	[4] -2	25 [4]	35 [2]	60	0
DEMAND	20	95	35	150	
Vⱼ	6	4	2		

Table-7.10

FROM ↓ / TO →	CHARLESTON	SEATTLE	LOS ANGELES	SUPPLY	Ui
TEXAS	6 +7	4 50	5 +3	50	0
CALIFORNIA	3 20	8 20	9 +3	40	4
ALASKA	4 +5	4 25	2 35	60	0
DEMAND	20	95	35	150	
Vj	-1	4	2		**590**

Therefore, if we were to choose Los Angeles, the cost of shipping would be 590 million USD.

Proposal

The financial analyses of these three alternative sites for the new refinery have been completed. Table 8 shows all the major *variable* costs (costs that vary with the decision) on an annual basis that would result from each of the three possible choices of the site. The second column summarizes what the total annual cost of shipping crude oil to all refineries (including the new one) would be for each alternative (as already given in table 7.2, 7.3, and 7.4). The third column repeats the data in table 7.6, 7.7, and7.8 on the total annual cost of shipping finished product from the refineries to the distribution centres. The fourth column shows the estimated operating costs for a refinery at each potential site, as earlier given in Table 6. Adding these three columns across gives the total variable cost for each alternative.

Table 8: Annual variable costs resulting from the choice of each site for the new Texaco refinery

Site	Total cost of Shipping Crude Oil ($ million)	Total Cost of Shipping Finished Product ($ billion)	Operating Cost for New Refinery ($ million)	Total Variable Cost ($ billion)
Los Angeles	695	1.57	620	2.885
Galveston	730	1.63	570	2.93
St. Louis	590	1.43	530	2.55

Conclusion

From a purely financial viewpoint, St. Louis is the best site for the new refinery, as the total variable costs associated with it comes to 2.55 Billion USD which is comparatively cheaper than the other two potential sites of this study. However, with any site selection decision, management must consider a wide variety of other factors, including some nonfinancial or qualitative factors. (For example, remember that one important advantage of the Galveston site is that it is close to corporate headquarters.) Furthermore, if ways can be found to reduce some of the costs for either the Los Angeles or Galveston sites, this might change the financial evaluation substantially. Management must also consider whether there are any cost trends or trends in the marketplace that might alter the picture in the future.

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